December 1st - December 4th, Orlando, Florida
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Videogame design for cognitive enhancement through micro-puzzle cognitive profiling

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(Serco in support of ADL)

Topics

- Intelligence and brain training
- Transference
- Evaluating games for coginitve potential
- Micro-puzzles in Portal 2
- Next steps

What does your IQ mean?

Can You Make Yourself Smarter?

Photo illustration by Clang

116+
17 percent of the world population; superior I.Q.; appropriate average for individuals in professional occupations.

121+
10 percent; potentially gifted; average for college graduates

132+
2 percent; borderline genius; average I.Q. of most Ph.D. recipients

143+
1 percent; genius level; about average for Ph.D.'s in physics

158+
1 in 10,000; Nobel Prize winners

164+
1 in 30,000; Wolfgang Amadeus Mozart and the chess champion Bobby Fischer.

20-50% of variation due to non-genetic factors
Genetic factors not like those of eye color but more like those for height and weight

www.nytimes.com/2012/04/22/magazine/can-you-make-yourself-smarter.html?_r=1&adxnnl=1&page

Crystalized vs. Fluid Intelligence

Crystallized Intelligence (*Gc*)

- Ability to use skills, knowledge, and experience
- Generally measured through vocabulary and general knowledge

Fluid Intelligence (*Gf*)

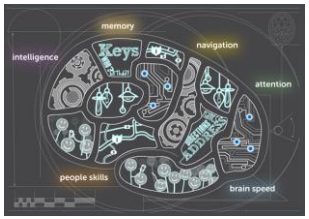
- Ability to analyze novel problems, identify patterns and relationships, and logic
- Inductive and deductive reasoning processes
- Positively correlated to working memory capacity
- Commonly measured through Raven's Progressive Matrices

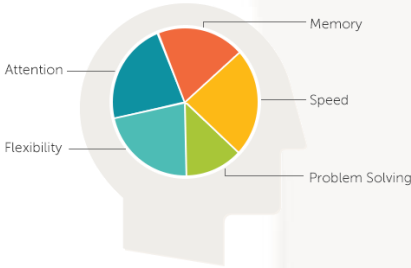
Can you increase your IQ...

by increasing cognitive capabilities through brain training?

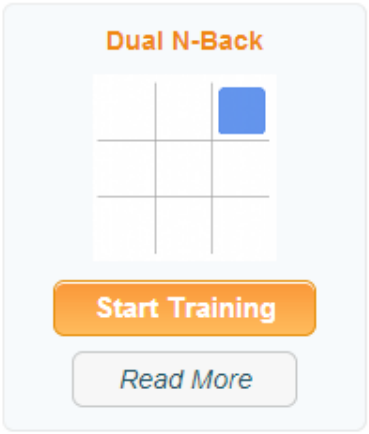
Fit Brains

lumosity





games for the brain



cog cognitive fun! Learn your mind. Play it too.

BETA MIND360 play smart

Research says…

- Jaeggi, Buschkuehl, Jonides, & Perrig (2008) performed a study that showed increased fluid intelligence (a cognitive capacity once thought to be fixed) as a result of performing a task (dual n-back task) that challenged working memory and divided attention.
- Klingberg (2010) confirmed that working memory itself is not a fixed trait, but a function that can be improved with "adaptive and extended training."
- Although replication has occurred, transfer to other measures is currently disputed by others in young healthy populations
- Most work done in clinical settings with positive transfer
- Jury is still out

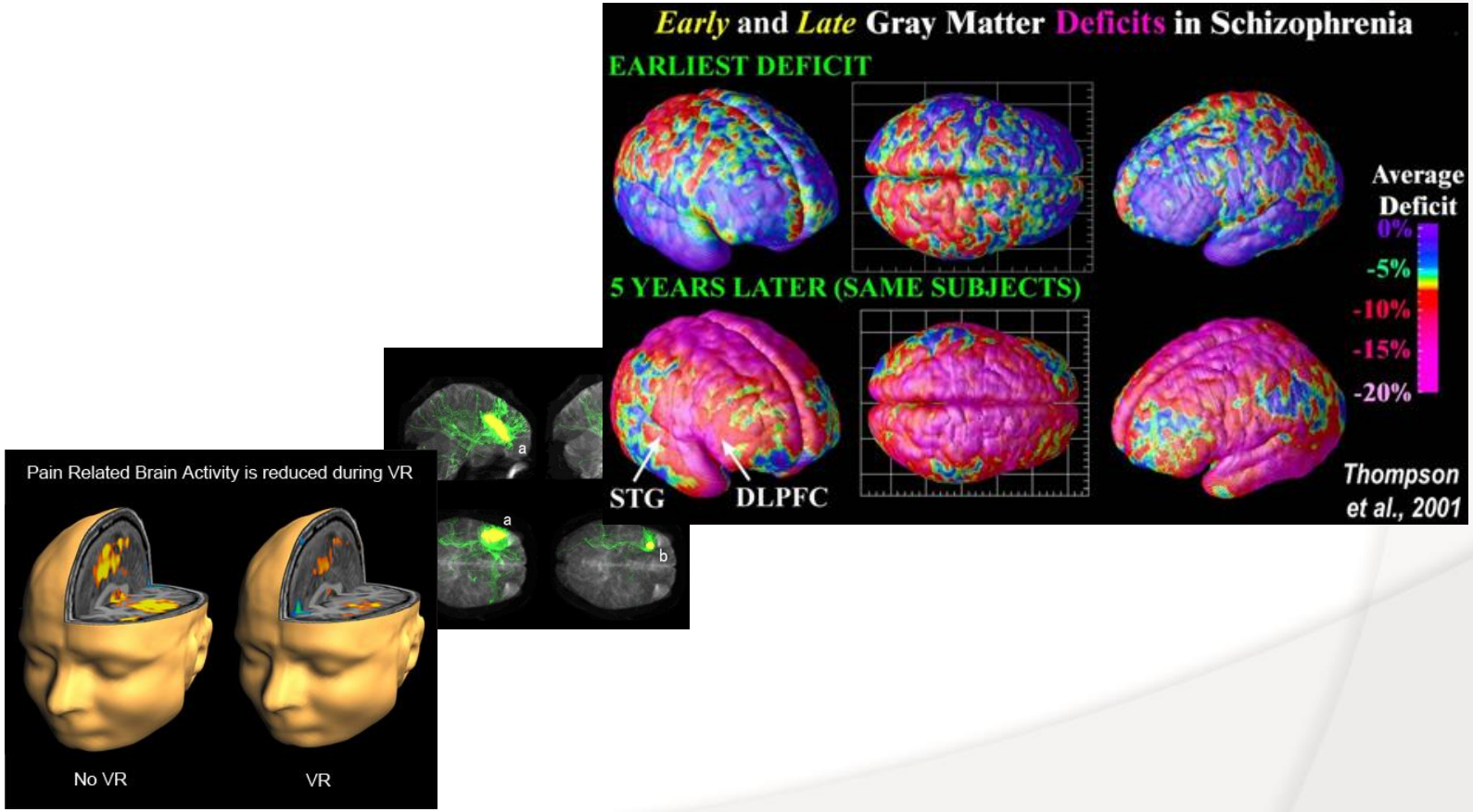
Research says...

However, games have shown promising results for the ability to positively impact cognitive abilities in young healthy adults.

- **Green and Bavelier (2003) - gamers performed better than non-gamers in measures of visual attention, and that the visual attention of non-gamers increased after playing action video games.**
- **Gallagher and Prestwich (2012) -**
  - 12 hours of mostly consecutive play of Portal 2 can result in increased focused attention
  - Those who reported playing video games for 19 or more hours a week scored higher in measures of spatial working memory, spatial sequencing, and cognitive planning.
- **Scanlon, Drescher, & Sarkar (2009) - playing brain-training games for 20 minutes a day, 5 days a week, resulted in improved working memory, visual attention, and executive function**

Can you increase your IQ…

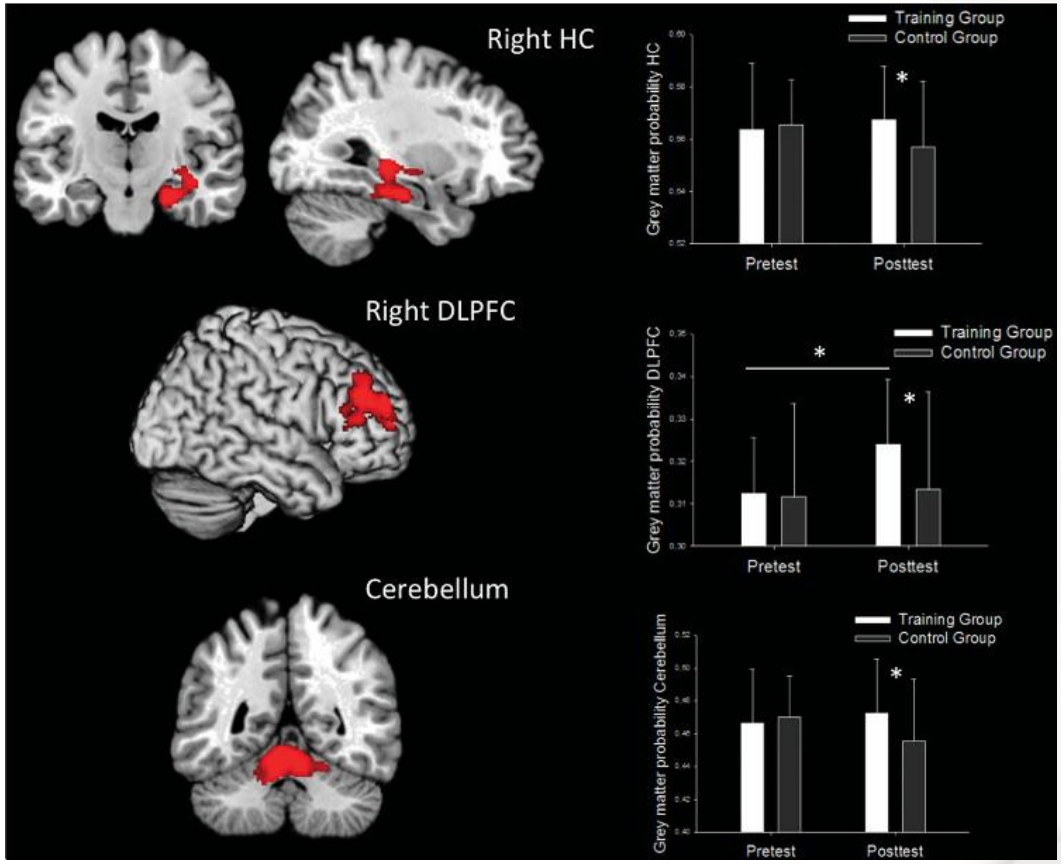
through brain structural changes (plasticity)?



Game play and physical brain changes

Using FMRI, German researchers found after playing Super Mario Bros for ≥ 30 min./day for 2 mos:

- increased brain plasticity
- gray matter increased in brain areas crucial for
    - spatial navigation
    - strategic planning
    - working memory
    - motor performance
    - …and are strongly correlated to measures of fluid intelligence



Brain regions showing a significant group (training vs control) Â time (pre vs post-test) interaction in gray matter volume. Bar graphs depict the interaction effects for the clusters displayed, error bars illustrate s.d., t-test, $p<0.05$. Acronyms: DLPFC (dorsolateral prefrontal cortex); HC (hippocampal formation.

Molecular Psychiatry (2014) 19, 265–271; doi:10.1038/mp.2013.120; published online 29 October 2013

Everyday activities lead to positive change

Being on "The Knowledge"

London taxi drivers have larger hippocampal volume than non-taxi drivers (Maguire et al, 2000)

The same is true for medical students and jugglers…

Transference of cognitive gains

- **Enhancing cognitive capabilities has a high potential for transference across domains**
- **As working memory capacities increased in children with ADHD, so did improvements in:**
  - Math reasoning performance (Holmes et al, 2009)
  - Word reading and reading comprehension (Dahlin, 2011)
  - Executive functioning (Beck et al, 2010)
  - Non-trained visuo-spatial working memory tasks and fluid intelligence assessments (Klingberg et al, 2002)
  - Inattention and hyperactivity/impulsivity (Klingber et al, 2005

Transference of cognitive gains

- Brain training in memory, reasoning, and processing speed in older adults resulted in slower declines in related, but not directly trained, instrumental activities for daily living (Ball et al, 2002 and Willis et al, 2006)
- Structured experiences in situations that demand an executive coordination of skills, such as complex video game environments, train a strategic control over one's cognition that shows transfer to different task environments (Hertzog et al, 2009).

Can cognitive capabilities be enhanced…

through game play with the right game designs?

If so, how?

That is our question….

Cognitive profiling of Portal micro puzzles

ADL 2013: Study to examine whether playing a commercial off-the-shelf game with five identified features will increase cognitive adaptability

Study site and population

Sheppard AFB, 18-24 year olds enlisted and lieutenants (N=39)

Random assignment to control/experimental groups

Design

Experimental – pre/post tests and *Portal 2*™ intervention

Correlational – history plus metacognitive awareness inventory

Pre/post measures

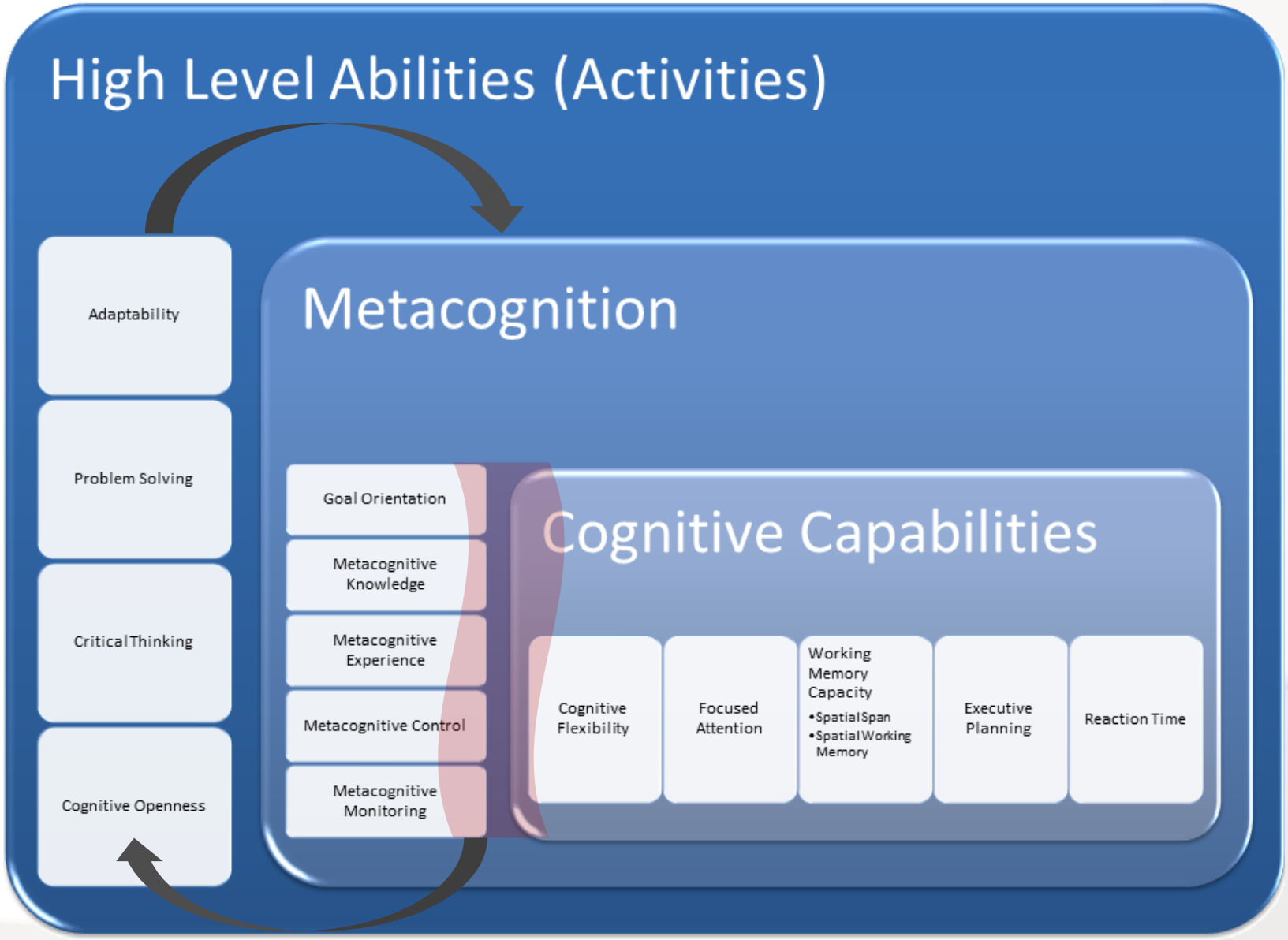
CANTAB customized battery

Metacognitive Awareness Inventory

Post measures

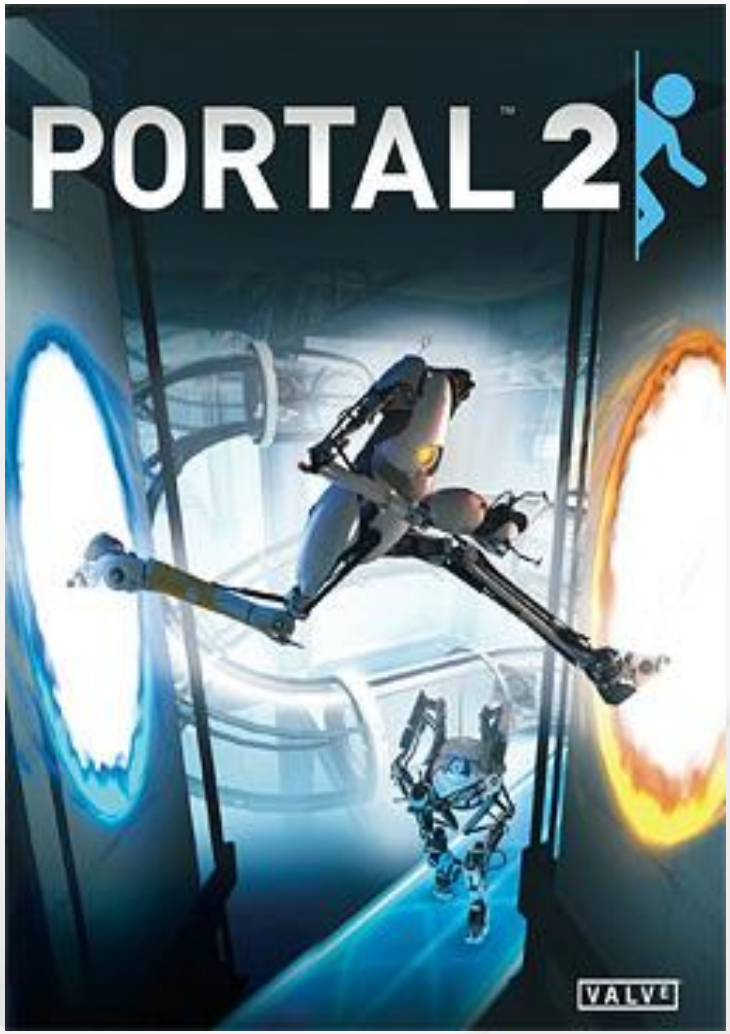
Game History Questionnaire

Cognitive Adaptability Construct



Why Portal 2?

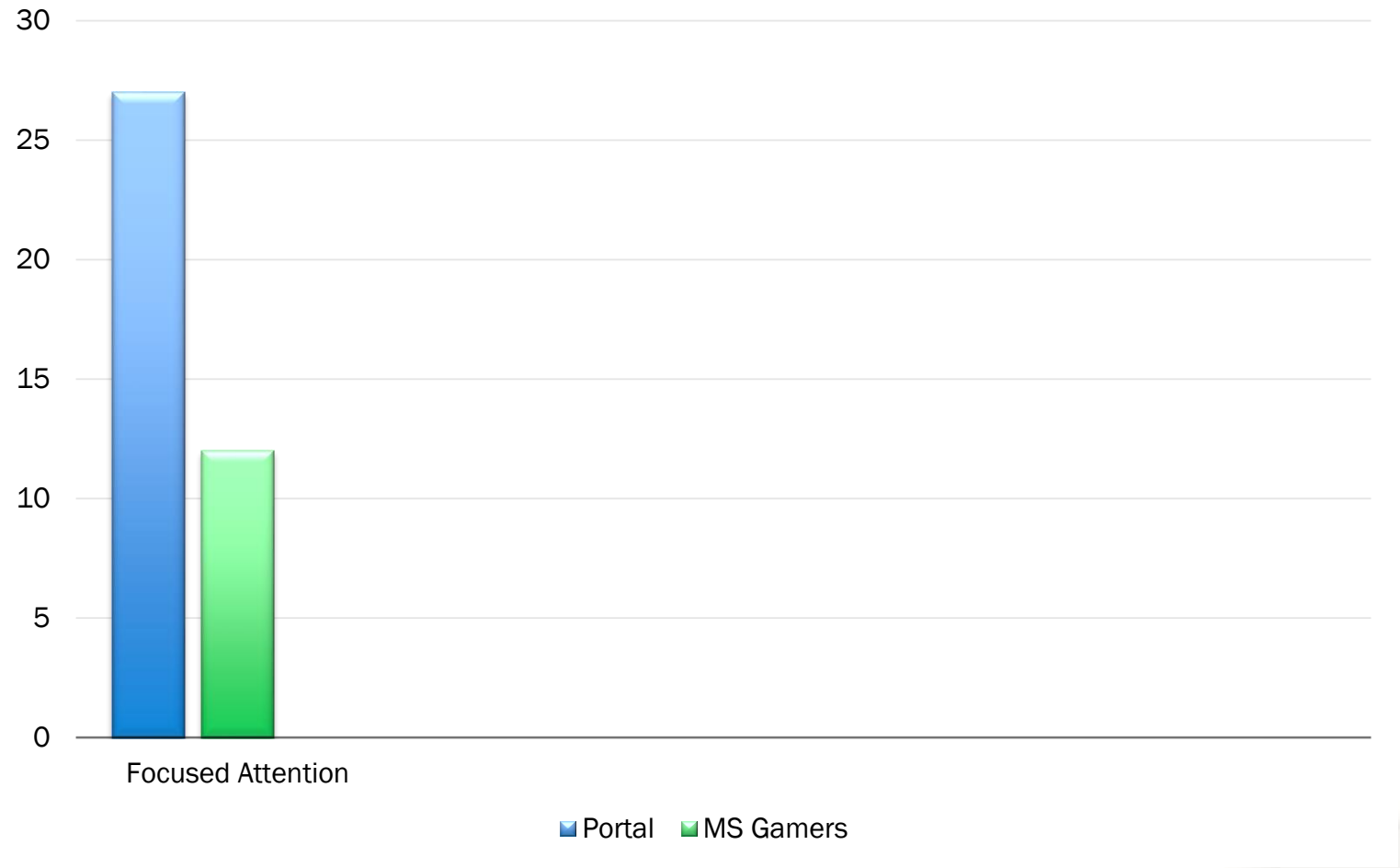
Features of CA					
Unstated/Implicit Rules	Unstated/Implicit Shifting of Rule Sets	Dynamic Shifting Environments	Open-Ended Gameplay	Implicit Reinforcement for Individual Actions/Choices to Achieve Final goal	Time X



CANTAB Battery (Cambridge Cognition)

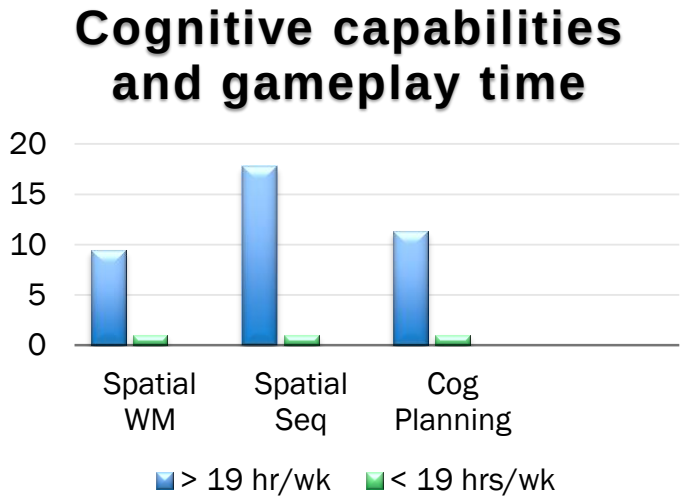
CANTAB Test	Definition/Cognitive Components
AST = attention switching	Switching attention between two qualities/attributes and ignoring task-irrelevant information in the face of interfering/distracting event
SSP = spatial span	Recall of sequencing as a function of placement in space
SWM = spatial working memory	Retaining spatial information and manipulating remembered items in working memory via heuristic strategy
RVI = rapid visual information processing	Sustained attention
OTS = one-touch stockings of Cambridge (executive planning)	Spatial planning, visualizing solution without acting, planning actions and understanding their consequences
RTI = reaction time	Time taken to react to stimuli; includes both movement time and response latency

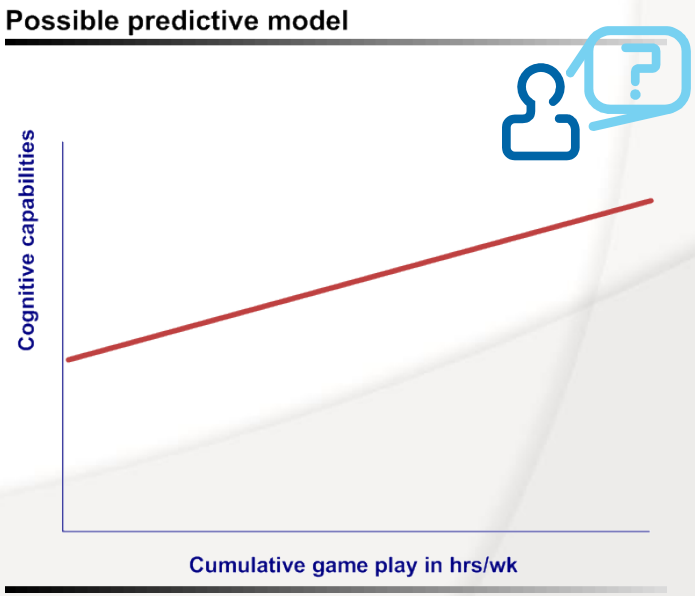
Portal 2 Intervention



Gaming Experience

- **Previous experience playing Portal 2 within past six months correlated positively with greater spatial working memory capabilities**
- **Historic gameplay of 19+ hours/week correlated positively with greater spatial working memory, spatial sequencing, and cognitive planning capabilities (high significance - p ranges from 0 to .006)**





Evaluating Games for Cognitive Potential

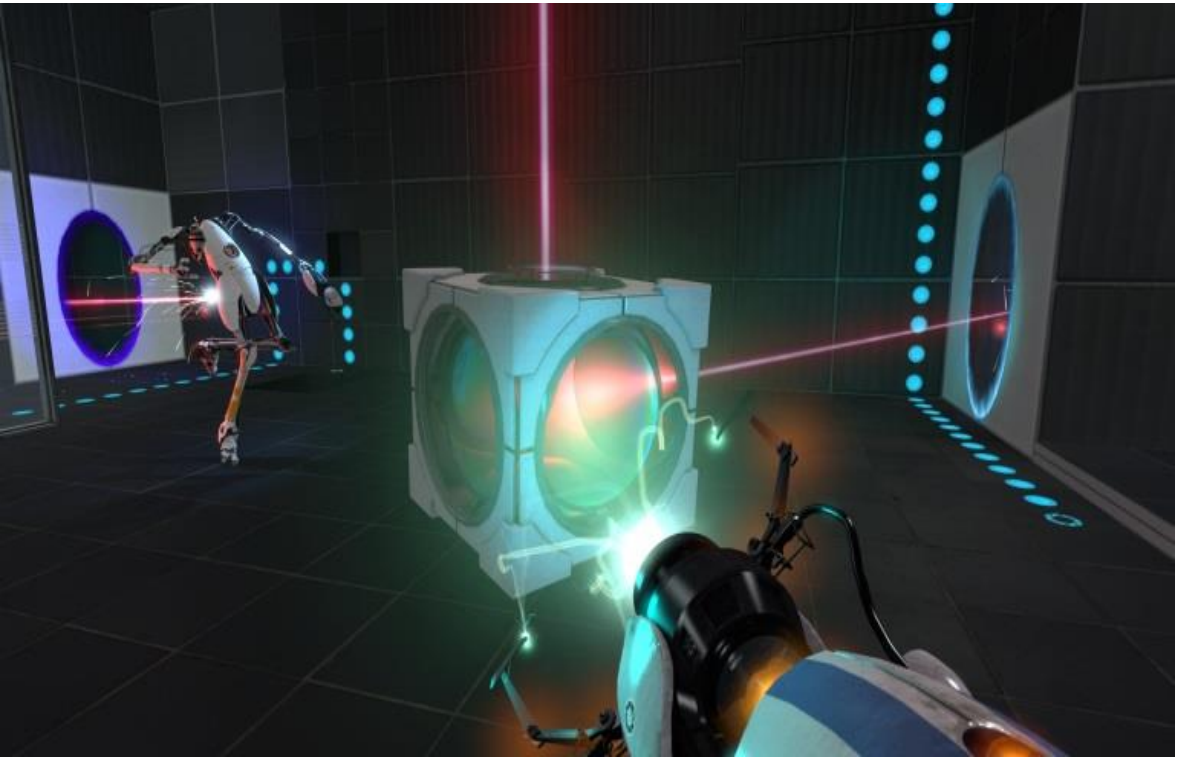
Cognitive Task Analysis (CTA) of Portal 2

- **Goal**
  - To capture and model behavioral and cognitive processes/activities for playing Portal 2 at the expert-level
- **Looked for**
  - Decision-making processes
  - Recognizing and responding to critical cues/environmental conditions
  - Tool utilization
  - Puzzles/micro-puzzles
  - Play reflection
- **Need to understand empirically**
  - Design of game
  - How game design interacts with player cognition
  - The presence of the five design characteristics posited to increase CA
  - Map the cognitive and mechanical requirements of successful gameplay in Portal 2
- **Outcomes**
  - Protocol developed for CTA on video gameplay
  - Persistent presence of all five cognitive adaptability design characteristics
  - Executive function requirements throughout

Portal 2 Micro-Puzzles

Cognitive Profiling

Micro-puzzles in Portal 2



- Nothing is a puzzle until it becomes a problem
- Solved puzzles become tools if used to solve other problems
- Puzzle may contain more than one micro-puzzle
- E.g. catching objects in mid-air, use of lasers through emancipation grills or utilization of momentum

Cognitive alignments

- **Portal 2 previously treated as "black box" – no specific identified alignments between**
  - Cognitive measures and micro-puzzle attributes
  - Between micro-puzzle types and design feature support
- **Potential cognitive alignments began to appear during cognitive task analysis**
- **Mapping alignments to cognitive assessment tasks logical next step**
- **Allow tailoring of levels/chapters in level builder to fit cognitive profiles**
- **Led to defining micro-puzzle definitions/typology**

Micro-puzzle typology

- **Function: Player has to induce the function of a tool or object in the game whose function is not explicitly revealed.**
  - Ex: Inducing that the function of the round, black, circular object on the wall (the "laser catchers," though not explicitly called so in the game) is to initiate some change in the environment, e.g., opening a door or raising a staircase from the floor, when activated by direct contact with a laser.
- **Feature-Function: Player has to induce the function of a specific (often newly-introduced) feature of a tool or object in the game whose function is not explicitly revealed.**
  - Ex: Inducing that the different sides of a reflection cube determine the direction a laser is redirected in when pointed at the cube.

Micro-puzzle typology

- **Usage: Player has to induce the ways in which an object, tool, or concept (e.g., laws of gravity or momentum) can be used to accomplish a task or goal (i.e., induce the intended or a beneficial interaction between player and object or concept).**
  - Ex: Inducing how to use the spring-loaded faith plates in order to propel the player to reach a certain space in the environment.
- **Relationship: Player has to induce the nature of a relationship between two or more objects, tools, or environmental features (i.e., how two or more things interact, and the nature of their interaction). This is often intertwined with solving a usage micro-puzzle.**
  - Ex: Inducing the relationship between a laser catcher and a laser, i.e., that the round object on a wall called a laser catcher is activated via contact with a laser beam, an interaction that then induces various changes in the environment.

Micro-puzzle typology

- **Action: Player has to induce how to take a particular action.**
  - Ex: Inducing how to make the player's avatar in the game catch an object in mid-air.
- **Sequence of Action: Player has to induce the proper sequence of actions needed to be taken in order to achieve a goal.**
  - Ex: Player has to induce the correct order to press buttons in order to activate portals to travel from location to location.

Micro-puzzle typology

- **Timing: Player has to incorporate the element of timing into their execution of an action in order for it to be successful in furthering their accomplishment of a goal or task.**
  - Ex: Player has to push a pedestal button to make a box drop into a portal, then push a second button at the correct moment as it comes out the other end to make a wall raise up momentarily from the floor, in order to stop the box's momentum and keep it from falling into the water (so that the player may then use it).
- **Rule Induction: Player has to induce a rule not explicitly given.**
  - Ex: Player has to induce that only one reflection cube can ever be present at a time in a given environment (and that if a second cube is introduced, the first one disintegrates).

Mapping to CANTAB

Micro-Puzzle Type	Definition	Hypothe-sized CANAB Test(s)	Design Feature Exemplified*
Function or Function-Change	Determining properties of an object ("thing," noun, etc) that define its nature and determine how it interacts with the surrounding world.	AST, SWM	1, 2, 3
Feature-Function or Feature-Function Change	Determining the function of specific features of an object (as opposed to the object as a whole).	AST	1, 2, 3
Relationship	Determining how one or more objects function or can function in relation to each other, including the outcome of interaction between one or more objects.	AST, SWM, OTS	1, 2, 3
Sequence of Action	Determining the sequence of mechanical and/or cognitive steps that must be executed in order to achieve a goal.	SWM, SSP, OTS	4, 5
Action	Determining how to perform an individual action (e.g., jumping, picking up objects).	OTS, SWM	1, 2, 4, 5
Usage	Determining how to use/interact with an object according to one or more of its intended or incidental functions.	AST, SWM, OTS	1, 2, 4, 5
Timing	Executing an action in accordance with the specific timing required in order to achieve a goal.	RTI, RVI, OTS	6
Rule Induction	Inducing implicitly presented rules from environmental/circumstantial clues.	AST, OTS	1, 2, 3

*Design Features

1. Implicit rules and rule sets
2. Implicit shifting of rules and rule sets
3. Dynamic, shifting environments
4. Implicit reinforcement for individual actions and decisions to achieve a final goal
5. Open-endedness

Current direction

- Design custom Portal 2 levels with Level Builder with puzzles aligning to specific cognitive properties
- Test and redesign for positive establishment of causality
- Fine tuning levels for specific cognitive enhancement properties
- Summative evaluation for cognitive function enhancement due to game interventions
- Develop and test for transference and total CA increases

Resources

Supporting Cognitive Adaptability Through Game Design
http://www.adlnet.gov/resources/supporting-cognitive-adaptability-through-game-design?type=research_paper
Can Game Design Be Leveraged to Enhance Cognitive Adaptability?
http://www.adlnet.gov/wp-content/uploads/2013/02/CA-Games-Design-EJeL-GAL-FNL-020313.pdf
Can Playing Video Games Improve Cognition and Adaptability?
http://www.adlnet.gov/from-adl-team-member-shane-gallagher-can-playing-video-games-improve-cognition-and-adaptability
The Cognition of Gameplay
http://www.adlnet.gov/from-adl-team-member-shenan-prestwich-the-cognition-of-gameplay
Cognitive Task Analysis: Analyzing the Cognition of Gameplay and Game Design
https://app.box.com/s/85tvzlmwv96v74yg1xnu
Transforming Education Through Neuroscience, Cognition, and Game Design
http://www.adlnet.gov/wp-content/uploads/2013/09/Transforming_Education_ITX3.pdf
Example Video
Portal 2 Cognitive Task Analysis: Ch. 1, Level 3

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Backup

Executive planning task example